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Perception of looming audiovisual motion in 6-year-olds: A high-density EEG study of full-term and preterm children

Master's thesis in Psychology
Supervisor: Audrey van der Meer
October 2022

Master's thesis

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Norwegian University of
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Abstract

Approaching objects on a collision course generate unique multisensory information which may signal danger or opportunity to the perceiver. The purpose of this study was to investigate whether there were any differences between full-term and premature 6-year-olds' cortical and behavioural responses to an audiovisual looming (approaching) stimulus (rotating circle) at three different speeds, using high-density electroencephalogram (HD-EEG). In addition, the children's motor skills were tested by using the Movement Assessment Battery for Children (M-ABC). This is the first study within the looming paradigm to report electrical overlap between auditory and visual modalities as a sign of audiovisual integration in 6-year-olds. During visual scanning of EEG data, observation was made of electrical activity moving in a trajectory from superior temporal sulcus/primary auditory cortex to visual cortex, and/or directly up to upper parietal brain areas, corresponding to cortical areas of the dorsal stream. Also, activity in visual cortex was observed to progress further up the dorsal stream and encountered the auditory activation in parietal regions. Our statistical analysis of time-to-collision of visual (VEP) and auditory evoked potentials (AEP) showed that full-term children's looming-related VEP and AEP responses were significantly closer to time-to-collision, compared to those of preterm children. Full-terms AEPs and VEPs were at relative equal time-to-collision, while the preterms VEPs were significant earlier than their AEPs in the looming sequence. Full-terms were found to adopt matching timing strategies between modalities, as both their AEPs and VEPs were at a relatively constant time-to-collision, regardless of the speed of the loom. This did not seem occur among preterms as their AEP values increased with decreasing loom speed, while their VEPs was relatively fixed on a constant time-to-collision. Overall, the results suggest that the preterm 6-year-old brain have poorer audiovisual integration than full-terms and may be compensating auditorily for an impaired visual motion perception. Preterm children also seem to have problems with estimating the loom's collision time, compared to the full-term children. The compensatory function of the auditory modality, reminiscent of a survival strategy, may be an explanatory factor to why we found no differences between preterms and full-terms motor performance.

Sammendrag

Motkommende objekter i kollisjonskurs mot individet genererer unik multisensorisk informasjon som kan signalisere fare eller mulighet. Hensikten med denne studien var å undersøke om det var noen forskjeller mellom fullbårne og premature 6-åringers kortikale og atferdsmessige responser til en audiovisuell looming (voksende) stimulus (roterende sirkel) under tre forskjellige hastigheter, ved bruk av høydensitet elektroencefalogram (HD-EEG). I tillegg ble barnas motoriske ferdigheter testet gjennom Movement Assessment Battery for Children (M-ABC). Dette er den første studien innenfor looming paradigmet som rapporterer om elektrisk overlapping mellom auditive og visuelle modaliteter som et tegn på audiovisuell integrering hos 6-åringer. Under visuell skanning av EEG-data ble det observert elektrisk aktivitet som beveget seg i en bane fra superior temporal sulcus/primær auditiv cortex til visuell cortex, og/eller direkte opp til øvre parietale hjerneområder, tilsvarende kortikale områder av dorsalstrømmen. Det ble også observert aktivitet i visuell cortex som beveget seg videre oppover dorsalstrømmen i møte med auditiv aktivering i parietale regioner. Vår statistiske analyse av tid-til-kollisjon av visuelle (VEP) og auditive fremkalte potensialer (AEP) viste at fullbårne barns looming-relaterte VEP- og AEP-responser var signifikant nærmere tid-til-kollisjon, sammenlignet med premature barn. De fullbårne barna viste AEPer og VEPer på relativt lik tid-til-kollisjon, mens pretermines VEPer var signifikante tidligere enn deres AEPer i den looming sekvensen. Fullbårne så ut til å ha matchende timing strategier mellom modaliteter, ettersom både AEPene og VEPene deres hadde en relativt konstant tid-til-kollisjon, uavhengig av loomens hastighet. Dette så ikke ut til å forekomme blant premature barn ettersom AEP-verdiene deres økte med synkende looms hastighet, mens VEPene deres var relativt fiksert på en konstant tid-til-kollisjon, uavhengig av loomens hastighet. Samlet sett tyder resultatene på at den premature 6 år gamle hjernen har dårligere audiovisuell integrering enn den fullbårne og kompenserer auditivt for en nedsatt visuell bevegelses persepsjon. Pretermine barn ser også ut til å ha problemer med estimering av loomens kollisjonstid, sammenliknet med de fullbårne barna. Den kompenserende funksjonen til den auditive modaliteten, som minner om en overlevelsesstrategi, kan være en forklarende faktor til hvorfor vi ikke fant noen forskjeller mellom premature og fullbårne barns motoriske ferdigheter.

Acknowledgements

Trondheim, October 2022

Silje-Adelen Slydal Nenseth

1. Introduction

In traffic situations, one must be alerted to avoid collision. If an approaching car honks at you, you will probably look in the direction the sound is coming from in order to better judge what behaviour you should respond with next. This is what is referred to as prospective control; the ability to plan and perform precisely-timed movements adapted to environmental changes (Lee, 1993; Van der Meer & Van der Weel, 2020), which depends on the ability to perceive what is going to happen in the near future (Agyei et al., 2016a; Van der Meer et al., 1994). Motion perception is a product of multisensory information processing, where sensory information from mainly audio and visual sources are integrated into a unified perception (Stekelenburg & Vroomen, 2009; Gordon & Rosenblum, 2005).

Looming refers to the last part of the optical event where an object is accelerating directly toward the eye (Kayed & Van der Meer, 2009). Audiovisual looming objects may signal danger or opportunity to the perceiver, which requires a dynamic interaction of functionally specialized, but widely distributed cortical regions for the ability to resonate with and act accordingly to the perceptual information (Hipp, Engel & Siegel, 2016). Findings from fMRI/PET studies suggest the following large-scale cortical regions to be highly involved in audiovisual collision judgement: the auditory (A1) (Van Atteveldt et al., 2007a; 2007b) and visual (V1) (Macaluso et al., 2004) cortices, the cortical pathway of the dorsal stream (Cappe, Thelen, Romei, Thut, & Murray, 2012; Tyll et al., 2013), and some regions crucial for multisensory integration, such as the superior colliculi (Calvert et al., 2001), the insula (Bushara et al., 2001; Lamichhane et al., 2016), and the superior temporal sulcus (Marchant et al., 2012; Noesselt et al., 2012; Stevenson et al., 2011, 2010). For integration of looming-related audiovisual stimuli, human neuroimaging studies point to superior temporal sulcus as the cortical site most consistently involved (Maier, Chandrasekaran, & Ghazanfar, 2008; Tyll et al., 2013), regardless of temporal (a)synchrony between the auditory and visual information (Zhou, Cheung & Chan, 2020).

When auditory and visual information are both available during motion perception vision is considered the primary sensory source (DeLucia et al., 2016; Zhou et al., 2007). However, the auditory components of an audiovisual looming object will be critical, especially if the visual components are somewhat blurred or occluded. Specifically, under the influence of an audiovisual approaching object, early auditory brain responses are thought to reinforce visual brain responses when the object is on a direct collision course (Leo, Romei, Freeman, Ladavas & Driver, 2011). Hence, the auditory system's functional role may be considered a

warning system for approaching objects, while vision provides relatively accurate temporal estimations, resulting in precise arrival time estimates (Regan & Vincent, 1995; Leo et al., 2011).

Although it is not the overarching function of the auditory modality, the capability of temporal estimations of collision based on auditory information has been demonstrated in adults (Gordon & Rosenblum, 2005; Gordon et al., 2013). However, auditory motion perception is found to be more prone to bias than visual motion perception, which may contribute to errors in auditory estimation of looming objects (McCracken & Neuhoff, 2021). The influence between the two modalities is considered bi-directional as visual information may also affect the auditory perception, in terms of the experience of sound loudness (McCracken & Neuhoff, 2021). Research on the rat brain, exposed to audio-visual congruent and incongruent stimuli, can perhaps explain this through the discovery of small parts of the lateral border of V1 responding to sound alone, as well as V1 being sensitive to the congruence of audiovisual information (Meijer, Montijn, Pennartz & Lansink, 2017). This may indicate that cross-modal integration should not be limited to specialized cortical association areas but extended to the primary sensory areas. Further, these findings indicate that V1 dynamically integrates non-visual information sources, while still attributing most of the resources to encoding visual information (Meijer et al., 2017). The sound sensitivity of V1 neurons enables not only integration, but also corrections, given the auditory modality being the one more prone to error in temporal predictions of the two (McCracken, & Neuhoff, 2021).

As infants develop and their mobility increases, they are dependent on adaptive neural structures that allow them to perceive motion and act accordingly (Van der Weel & Van der Meer, 2009). Neural pruning in the normally-developing brain is shown to gain white matter (myelin) volume and reduction of grey matter (neurons) volume from early age into early adulthood, due to long-term dynamic change under the influence of external stimuli (Webb, Long, & Nelson, 2005; Constable et al., 2008). Following this, a more sophisticated processing of perceptual information can be expected as the fewer neurons become more specialized, while signal transmission becomes more efficient (e.g., Constable et al., 2008). Disturbance/damage to the neural structures, on the other hand, may lead to impaired functional integrity resulting in less sophisticated or precise signal transmission in response to perceptual information (Agyei, Van der Weel & Van der Meer, 2016).

The dorsal stream, important for motion perception and planning of movement, is associated with the overall processing of visual information (Cappe et al., 2012; Tyll et al., 2013). The retina, central visual pathway and visual perception develop during the last weeks of fetal life and may therefore suffer from an abnormal developmental course if disrupted by premature birth (Hammarrenger et al., 2003; Delafield-Butt et al., 2018). Thus, the development of the dorsal stream is found to be particularly vulnerable in those born prematurely because it is not yet fully maturated in terms of readiness to interact with environmental changes (Braddick et al., 2003). Neurological damage on the retina (especially rods), as well as disruption of the myelination of the central visual pathway may compromise the dorsal stream function as these damages lead to loss of visual information in the signal transmission to V1 (Hammarrenger et al., 2003).

Further, very low gestational age (<32 weeks) and low birthweight (< 1500 g) are found to heighten the risk of developing visual impairments, low- and high-level motion perception, motion-defined form perception, and visuomotor control (O'Connor et al., 2004; MacKay et al., 2005) due to damage to the higher cortical white matter (myelin) tracts (Kelly et al., 2016). A longitudinal volumetric MRI study on preterm (age: < 30 gestational weeks, weight: 600 to 1250 g) children revealed a disturbance in the trajectory of cerebral development during late childhood (5 years) and early adolescence (17 years), compared to full-term children (Constable et al., 2008). Specifically, the preterm children showed both lower grey matter reduction and less white matter gain in temporal and parietal regions over time compared with the control group born at term (Constable et al., 2008; Weinstein et al., 2012). This may be reflected in problems with sustained attention, visuospatial processes, spatial working memory, and perceptuomotor problems (Braddick et al., 2003; Vicari, Caravale, Carlesimo, Casadei, & Allemand, 2014; Taylor, Jakobson, Maurer, & Lewis, 2009).

Recording of avoidance behaviour such as blinking is established as the most reliable method to investigate awareness and prospective actions to colliding objects among infants. Research in this area shows that preterms have problems timing their avoidance (blinking) behaviour in relation to a looming object, especially in response to the faster approaching looms (Kayed, Farstad and Van der Meer, 2008). They do not show a developmental trend where the blinking becomes more precisely timed in relation to the loom's collision by the age of 12 months, as shown by full-term infants, indicating problems with development of looming-related prospective control (Van der Meer et al., 1995; Kayed & Van der Meer, 2000; 2007; Kayed, et al., 2008).

A study on auditory guided rotation among 6- to 9-month-old babies has contributed to a greater understanding of the auditory system as a functional listening system where auditory information is used as a perceptual source for prospective behaviour Van der Meer, Ramstad & Van der Weel (2008). The infants lay in a prone position with magnetic trackers on their heads and bodies that measured their rotation direction and velocity while they responded to their mother's voice. The results showed that the children consistently chose the shortest path over the longest to rotate to their mother standing behind them. Their ability of prospective control was demonstrated by rotating with a higher peak velocity as the angle to be covered between themselves and their mother's position increased (Van der Meer et al, 2008). A similar study has not been conducted on preterm infants. However, the behavioural studies have provided a basis for investigating further by analysing the functional brain activity that underlies prospective behaviour.

With the aim of investigating the underlying cortical responses to an audiovisual loom accelerating at three different speeds on a collision course, high-density (HD-) EEG proves to be a promising method (Agyei et al., 2016). During analysis of HD-EEG data, a head model providing a rotatable 3D mapping of the brain, build-up (negative) and declining (positive) voltage activity in distinct brain areas over time, in response to the approaching looms, is visible to the naked eye. During thorough visual inspections, findings have been made of dense and well-centred looming-related visual evoked potentials (VEP) in the occipital and parietal areas (Van der Weel & Van der Meer, 2009; Van der Meer, Svantesson & Van der Weel, 2012, Van der Weel, Agyei, & Van der Meer, 2019), as well as prominent auditory evoked potentials (AEP) in the upper parietal areas in infants (Agboada, Van der Weel & Van der Meer, 2015; Saeed, 2018), without reports of electrical overlap with other brain activity.

The time-to-collision values of looming-related cortical activation are used in further investigations of temporal predictions of the audiovisual loom, as well as how the interaction between the activity in the auditory and visual modalities occurs (e.g., Van der Weel et al, 2019). Full-term infants show significantly improved timing of looming-related brain responses as their VEP responses are shown to become increasingly shorter and take place at a fixed time-to-collision, regardless of loom speed, by the age of around 12 months (e.g., Van der Meer et al., 2012). This indicates looming-related prospective control by the first year of life, which results in precise blinking responses in time before collision occurs (e.g., Kayed et al., 2008). Further, full-term infants' attention towards the loom seems to be visually dominant, as they show AEP responses earlier at, and with higher variance, compared to their

VEPs responses, at 8-10 months of age (Agboada et al., 2015; Saeed, 2018). This points to the enhancing role of the auditory system to visual motion perception (Leo, Romei, Freeman, Ladavas & Driver, 2011). Further, the AEPs of 3-4-months old infants occur earlier in the looming sequence that the AEPs of 9-10-months old infant, indicating a developmental trend (Agboada et al., 2015). At 6 years of age the children continue the developmental trend, by showing VEP responses even closer to the virtual collision (Vilhelmsen, Van der Weel, & Van der Meer, 2021; Rodríguez, 2021). AEP and behavioural responses at 6 years of age are yet to be investigated.

No EEG studies examining the interaction between AEP and VEP in preterm children (with no known neurological damage) have been found. Nevertheless, HD-EEG studies show preterm infants having problems with visual perception of looming objects, compared to full-term infants (e.g., Vilhelmsen et al., 2021). Specifically, they show very early VEPs in the looming sequence, and with high variance, throughout the first year of life, compared to full-term infants, which indicates problems in estimating the collision (Van der Meer et al., 2012; Vilhelmsen et al., 2021). These results reflect preterms' difficulty with timing their blinks in response to the looms (e.g., Kayed et al., 2008). Improvement is shown later, at the age of 6 years, as their looming-related VEPs by this age are much closer to the looms' time-to-collision, and at a fixed time-to-collision regardless of loom speeds (e.g., Vilhelmsen et al., 2021; Rodríguez, 2021). However, they still show higher variability, and have VEP time-to-collision values almost twice as large as shown by the full-term children at 6 years of age (e.g., Vilhelmsen et al., 2021).

The 6-year-olds were instructed to press a button (BP) when they believed that the virtual loom (an approaching ball) would "hit" them (Rodríguez, 2021). Interestingly, Rodríguez (2021) did not find any differences between preterm and full-term 6-year-olds`prospective responses (BP) to the loom. These findings are in line with previous research pointing to improved motor skills among preterm children (Cserjesi et al., 2012; Broström et al., 2016).

The experiment also contains a looming sound synchronized with the virtual loom, which still remains to be investigated. Therefore, in this study we aimed to replicate the findings of Vilhelmsen et al. (2021) and Rodríguez (2021), and complement this by adding analysis of auditive brain responses as well in full-term and preterm 6-year-olds. As a supplement, we compared preterm and full-term motor skills, using the Movement Assessment Battery for children (M-ABC) (Henderson & Sugden`s, 1992).

The present study explored audiovisual integration during exposure to audiovisual looms approaching on a collision course at three different speeds (fast, medium, and slow), as well as investigate behavioural responses (button press) to the looms, among full-term and preterm 6-year-old children. We expected full-term children to show average looming related VEPs and AEPs significantly closer to time-to-collision, than those of preterms. Further, we expected both full-terms and preterms` VEPs and AEPs to be at a relatively fixed time-to-collision, but with higher variability among preterms. For the children's motor performance, we expected preterms to show less accuracy in their looming related prospective responses (button press), than full-terms. Further, less accuracy among preterms than full-terms` motor skills in the M-ABC test was expected as well.

2. Methods

2.1 Participants

A total of 20 healthy children, 10 full-term born and 10 prematurely born, at the age of 5-6 years took part in this experiment. Most participants were already recruited and taken part as infants through birth announcements and with help of the leading paediatrician at Neonatal Intensive Care Unit at St. Olav`s University Hospital in Trondheim, Norway. Others volunteered via parents with connections to the university, or as siblings of previous participants.

None of the preterm children had any neurological deficits such as cerebral palsy or retinopathy associated with prematurity, or other perinatal issues requiring medical treatment that may lead to abnormal development. Both groups were matched at age and gender. The full-term born group of 4 girls and 6 boys had a mean age of 6 years and 3 months ($SD= 9$). The prematurely born group of 6 girls and 4 boys had a mean age of 6 years and 2 months ($SD= 7$ months). The mean gestational age for the full-term born children was 39 weeks and 8 days ($SD= 1$, range= 37 - 41 weeks), and their mean birthweight was 3652 g ($SD= 594$, range= 3300 - 5120 g). The prematurely born children (moderate to very premature) were born at a mean gestational age of 31 weeks and 5 days ($SD= 1.2$, range= 26 - 32 weeks) with a mean birth weight of 1608 g ($SD= 515$, range= 710 - 2670 g).

The study has been approved by the Norwegian Data Service for Social Science and the Norwegian Regional Ethics Committee. The physiological procedures conducted in this study causes no harm or pain to the participants. Parents gave their informed consent prior to the testing. The participants were made aware that they were free to withdraw from the study at any time, for whatever reason.

2.2 Looming Stimulus

On a white background, the visual looming object was simulated as a black 2D circle rotating with a constant angular velocity of 300 degrees per second on a collision course towards the child (See Figure 1 a)). Within the black circle four smaller circles (blue, green, red, and yellow) with a radius of 1/3 of the black circle were rotating.

A simple harmonic tone, representing the auditory loom, was programmed to mimic a natural sound approaching the child on a direct collision course. The looming sounds were all sampled at a rate of 44.1 kHz, and a constant intensity level of 60 dB.

The experience of a collision was created by the auditory and visual stimulus programmed to appear simultaneously, making a looming object accelerating at three different speeds in a symmetrical manner. The speed conditions were 2 seconds (-21.1 m/s^2), 3 seconds (-9.4 m/s^2), and 4 seconds (-5.3 m/s^2), presented randomly to avoid sensory adaptation. At stimulus start, the visual loom was at a 5º visual angle (diameter of 6.5 cm) and a virtual distance of 43.1 m for 1 second, then expanding during a looming phase until it finally reaching its largest size at a virtual angle of 131º (diameter of 350 cm) and distance of 0.8 m, irrespective of speed conditions. A one-second lasting white screen without sound was presented between each trial to avoid sensory adaptation. For the auditory loom, the sound increased in pitch, from a one-second lasting 140 Hz, then increasing up to 460 Hz by stimulus end, meaning that the sound went from being barely audible to becoming loud enough to simulate a virtual collision of a looming sound. A "whoop" effect of the sound appeared at its loudest, exactly at the same time when the visual loom would make a collision with the child (see Figure 1 b)).

a)
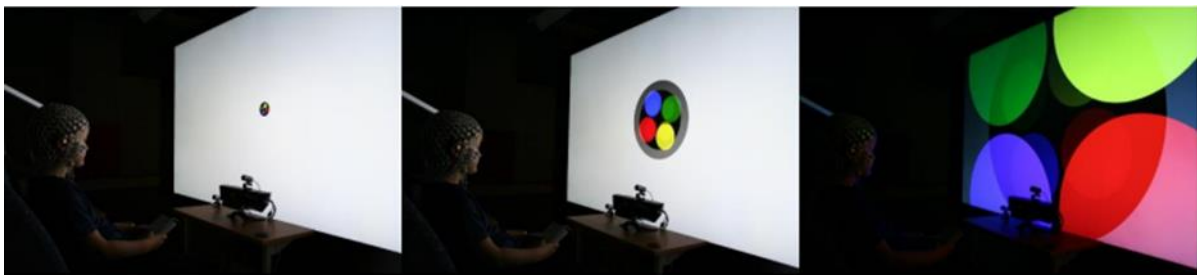
b)
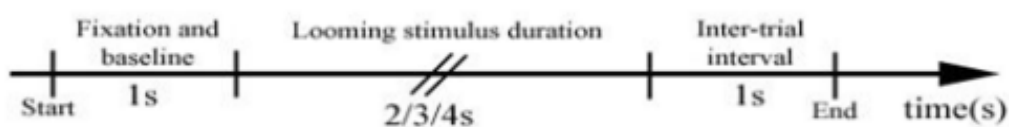
Figure 1. a) The Experimental setup, and a diagram of the stimulus configuration a) The child sitting in the chair, were instructed to hold the response pad in their lap and look at the screen which displayed the 2D virtual loom approaching in collision course towards them. The auditory looming stimulus was presented synchronously with the visual stimulus by Logitech speakers. **b)** A timeline showing the approach of the looming stimuli and the time duration during, fixation, looming stimulus, and inter-trial interval from the onset and offset of a single looming trial. Figure adapted with permission from Van der Meer et al. (2012).

2.3 Apparatus

The virtual looming visual motion scene was generated by using E-Prime 2.0 (Psychology Software Tools). The scene was projected onto a mirror reversed screen measuring 1.1 m by 0.8 m and a refresh rate of 60 Hz. The participants were placed in an electrically adjustable

chair and viewed the screen from a distance at about 75 cm at a visual angle of 68° by 47° (see Figure 1).

EEG brain activity was recorded using Geodesic Sensor Net (GSN) 200 containing 128 or 256 (depending on the participants' head measurements) Ag/AgCl sensors evenly distributed on the participants' head (Tucker, 1993). A high-input EGI amplifier was connected to the GSN setup and impedance was kept below 50kΩ, to ensure a sufficient signal detection and amplification (Budai, Contento, Locatelli & Comi, 1995; Ferree, Luu, Russel & Tucker, 2001; Picton et al., 2000). Net Station, runed by a Macintosh computer, made recordings of the EEG data with a sampling rate 500 Hz and an online low cut-off filter set at 200 Hz and a high cut-off filter at 0.1 Hz. Net Station was connected to E-Prime to receive triggers for the onset and offset of the looming stimuli. Tobii X50 eye tracker monitored gaze and was processed by ClearView software. Two digital cameras were installed in different angles to check for movements during the experiment in the offline analysis.

A response pad with four 10 * 2 cm rectangular buttons was provided to the participants with the instruction of pressing the button when the loom "crashed" with them. The children could press several times during one trial, but only the last button press (BP) response was stored by Net Station Software. The last recorded BP could occur both before and after stimulus end.

2.4 Movement Assessment Battery for Children (M-ABC)

Henderson & Sugden`s (1992) Movement Assessment Battery for Children (M-ABC) was used for assessment of the participants' motor skills. The battery contains three categories of tests: Manual dexterity, Ball Skills, Static and Dynamic Balance, with eight standardized tasks within each respective category. Participants performed the motor task corresponding to the test version of their age; in this study at the age of 4-6 years. An assistant explained and escorted the participants through each physical task in accordance with the M-ABC guidelines, while another assistant rated the score of performance and made videorecording of the session. The video recording was stored if it was found necessary to return to it to check the results.

2.5 Procedure

All procedures and recordings took place at the Developmental Neuroscience Laboratory at NTNU Dragvoll campus, Trondheim.

Each participating child came to the laboratory with one or both parents by separate agreements. During the welcome, the child was given some time play and to get to know the laboratory while the experimenter was talking with the parent(s). The experimenter informed the parents about the aim of the study and that they could withdraw their child from the study at any given time. When the parent(s) had given their signed written informed consent, we continued with preparation for the EEG testing. Head measurements was taken on the child to select the appropriate size of EEG net. The net was soaked in a lukewarm saline solution which enhance the conductivity. After the net had been placed on the child`s head, the child was led into the experimental room. The children were free to bring their parents with them for support. However, the parents were instructed to not intervene during testing if the child did not seek their parent. The experimental room was prepared with insulated power cables and electrical noise-insulating wall panels to reduce interference to the EEG recordings. All personal electrical devices had to be left outside of the experimental room, and power supply to the adjustable chair was disconnected prior to the onset of the experiment.

The child was kindly asked to find a comfortable sitting position that made it possible to sit still and watch the screen for a longer period. The net was connected to the amplifier as soon as the child was sitting comfortably. An assistant in the control room, which was separated from the experimental room by a window, checked the quality and strength of the EEG recording when the net was connected to the amplifier. If something prevented signal recording, necessary adjustments were made, such as massaging electrodes closer to the scalp or adding more electrolyte solution to the sensors with a pipette.

The children were handed a keypad with four keys to press on when they believed the loom "crashed" into them on an average of 65 trials (*SD*= 12, range= 44 - 88). In order to reduce noise from muscle contractions, the children were instructed to keep the pad resting in their lap with both hands.

Then the session started with four different visual motion experiments of an average of 4-6 minutes each, including the looming experiment as number three in the sequence. If at any point the child became tired or restless, the experiment could be paused. If the child still

found it difficult directing their focus back to the screen after a break, the session was ended. After the session, some refreshments were arranged before we continued with the M-ABC.

All children completed the entire EEG session and M-ABC. The M-ABC session lasted for about 30 minutes, with a possible score between 0-40 points based on both test results and a tick-off form completed by the accompanying parent. A total score of 13.5 or higher would indicate an impaired motor development. The parent(s) was welcome to quietly observe the session, but in most cases, they sat and filled in the tick-off form in the next room.


2.6 EEG-data analyses

The EEG recordings were first segmented and exported as .raw files through Net Station software and transferred via a memory stick to the laboratory's secure server with limited access. Before proceeding with the analyses, a colleague anonymized the data material so that all data analysis took place blinded, and thereby avoid being biased by knowledge of the participants' group affiliation. All data processing and analysis was performed with BESA (Brain Electrical Source Analysis) version 6.1. In BESA, a channel configuration and digitized head surface points, corresponding to the EEG Geodesic Sensor Net used, were added for each participating child before processing began. In the EEG data, the notch filter was set to 50 Hz to remove mainline noise interference, the low-cut-off filter (high band pass) was set to 1.6 Hz to remove low drift in the data, and the high cut-off filter (low band pass) was set to 50 Hz. Through visual inspection, trials with "bad" channels contaminated with noise (e.g., winking, muscle contractions, eye movements) were either removed, or noise reduced (interpolating). Whether a channel was marked as "bad" depended on whether the noise continued to be present after interpolating. None of the participants had more than 10% of the channels marked as "bad", so that sufficient data was retained to make a valid analysis. A reference free montage setting was used, showing EEG at 27 standard electrodes, in order to simplify the data for easy analysis.

2.6.1 VEP and AEP selection

During visual scanning, it was checked whether the brain activity arose as a result of noise for each trial (e.g., winking, muscle contractions, eye movements), so that the patterns of brain responses presented were related to the audiovisual loom to the highest possible degree. Visually evoked potentials (VEP) and auditory evoked potentials (AEP) represent the event-

related potentials (ERP) in the visual and auditory cortices, respectively (Luck, 2005; Nunez & Srinivasan, 2006). For an easier detection of peaks, high-cutoff filter was set to 8 Hz. The criteria for selecting peaks were based on a visualized 3D mapping model of the build-up (negative) and declining (positive) voltage activity, as well as visual inspection of peaks on a trial-by-trial basis. Prominent looming-related VEP responses were marked in electrode site Oz and Pz , and prominent looming-related AEP responses were marked at electrode Cz (see Figure 2 a) and b)). If more than one VEP or AEP peak was found in a trial, a decision was made based on the following criteria: highest amplitude and/or closest to stimulus offset, and preferably in correspondence with the overall individual activation pattern of the given child.

a)
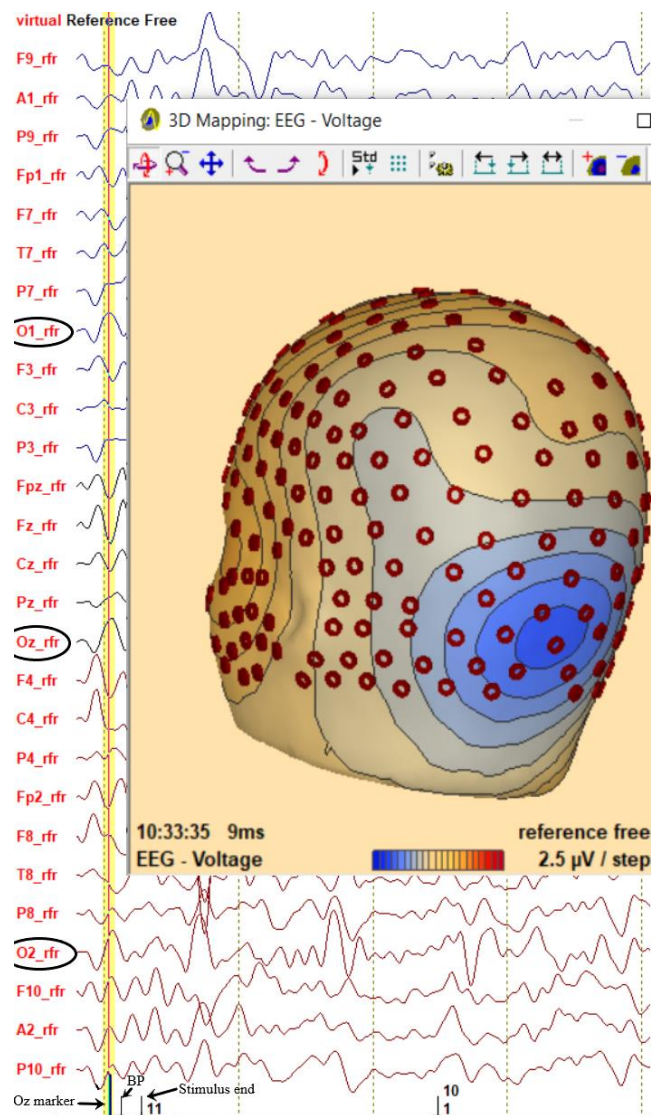
b)
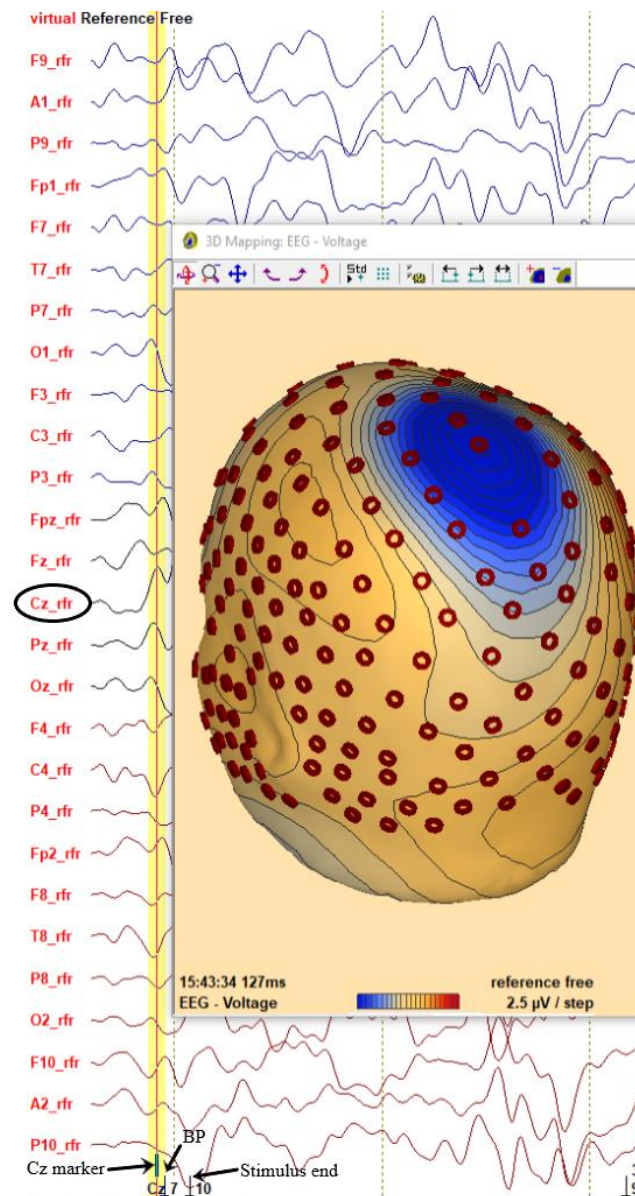
Figure 2. Raw EEG data illustrating a prominent looming-related VEP peak in Oz **(a)** and prominent AEP peak in Cz **(b)**, using a standard reference free montage of 27 electrodes. VEP can be observed in Oz (and O1/O2), and in Pz which is slightly further up from Oz. AEP can be observed in Cz. The yellow vertical line helps finding the peak top before marking them manually in BESA. The VEPs time-to-collision (-235 ms, slow loom), and AEPs time-to-collision (-167 ms, medium loom) is viewed as a direct response to the looming stimulus, calculated by the remaining time from top of the peaks to stimulus end. Button press (BP) was recorded during the EEG experimental session, and its timing error is calculated by the remaining time from BP occurring to stimulus end. Example **a)** and **b)** have been chosen based on the prominent appearance of the peaks so that the location and electrical activation are clearly visible to the reader.

Selection of AEP`s and VEP`s, required a return to the EEG data material multiple times with a fresh pair of eyes. This to be able to find similar patterns of looming-related activation across participants and becoming well acquainted with individual looming-related activation patterns of each child. For example, although the looming-related VEPs arose in visual cortex in all participants, some participants showed repeatedly VEPs in visual cortex lateral left, while others showed typical patterns of VEPs in visual cortex lateral right, related to handedness.

Observed peaks were marked according to trial number and electrode channel while working in BESA, which when the selection was completed, was extracted from BESA to a separate spreadsheet (.evt file), per participant. The spreadsheet showed an exact overview of all marked timestamps of VEPs and AEPs, as well as the recorded BPs, in which time-to-collision was calculated from the remaining time from marked peak/BP to stimulus end, on a trial-by-trial basis. These values were extracted in milliseconds (ms) from the spreadsheets for further statistical analysis.

2.6.2 VEP and AEP analysis

Averages of VEPs and AEPs response values of both full-terms and preterms were used to investigate whether there was a difference between full-terms and preterms' average time-to-contact, using ANOVA statistics.

2.7 Behaviour analysis: Prospective responses (RMS values for button press)

As our interest was to investigate whether there were differences between full-term and preterm born looming-related prospective responses, button press (BP) recordings were conducted for each trial. A BP-response time-to-contact value of 0 corresponded to a perfect behavioural response according to the loom's time-to-collision. Still, it was expected that the participants did not have perfect behavioural responses. The children's BP responses could potentially occur either before or after the end of the looming sequence, meaning that the values could be either positive or negative, respectively, unlike the brain responses which always occurred before the end of the trial. A Root Mean Square (RMS) averaging procedure was therefore used to overcome the problem for the statistical analysis.

2.8 Behavioural analysis: M-ABC

For each child, M-ABC scores (Manual dexterity, Ball Skills, Static and Dynamic Balance) were added together. The total score represented their individual motor skill level within their age group. A total individual score of 13.5 or higher would indicate an impaired motor development. A two-tailed t-test was conducted to examine the difference between full-term and preterm 6-year-olds' motor skills.

3. Results

The full-term children provided a total of 234 (*M*= 30, *SD*= 5, range= 23 - 38) trials, and preterms provided a total of 270 (*M*= 27, *SD*= 12, range= 13 - 46) trials where BPs and looming-related VEPs, AEPs co-occurred within the same trial. In total, the children provided 774 trials where the BPs co-occurred with any of the two looming-related brain responses, of which full-terms provided 371 (*M*= 37, *SD*= 7, range= 28 - 49) and preterms provided 403 (*M*= 40, *SD*= 13, range= 13 - 56). Looming-related peaks were more or less evenly distributed among the full-terms and preterms, with a higher number of VEPs than AEPs.

3.1 Moving patterns of looming-related brain activity observed by visual scanning

Independent looming-related event related potentials (ERP) was observed in occipital areas corresponding to electrodes Oz and Pz (VEP), as well as in parietal areas corresponding to electrode Cz (AEP), as expected based on previous research on baby data (Agboada et al., 2015; Saeed, 2018). Independent refers to negative voltage building up and fading out at one specific location (e.g., Oz or Cs), without any overlap with electrical activity from other brain locations (see Figure 2 a) and b)). However, in contrast to the baby data, a new trend was observed among many participants showing prominent AEPs occurring much closer to time-to-contact than the VEPs in the looming sequence. With regard to the fact that these AEPs did not appear to be caused by noise and were within an accepted time-to-collision (about -200 ms and -300 ms before time-to-collision), it was decided to keep them for further analyses. Next, observations of patterns of moving/floating electrical activity have been made and two main findings will be described here.

First, a looming-related activation was observed in electrode T7/P7 and/or T8/P8, corresponding to the superior temporal sulcus/A1 in a path directly up to and activating a prominent AEP in the parietal brain area, corresponding to electrode Cz, and the upper parts of the dorsal stream. This was typically followed by VEP activation in electrode Oz/Pz, which occasionally progressed upwards and overlapped with the activity in Cz, enhancing the activation there. The pathway described from Oz/Pz and upwards corresponds to the first parts of the dorsal stream pathway. In the trials where the choice was between two peaks in Cz, the one with time-to-collision closest to the loom was chosen for further statistical analyses.

Another observation was made of a moving activity pattern emerging from around electrode T8/P8 and/or T7/P7, before traversing backwards to Oz and/or Pz, meeting and reinforcing

the VEP in Oz/Pz. This may point to the auditory reinforcing influence on the looming-related activation in V1. Occasionally, the activity travelled from Oz/Pz up to Cz, as with the first mentioned trend of moving brain activity (see Figure 4).
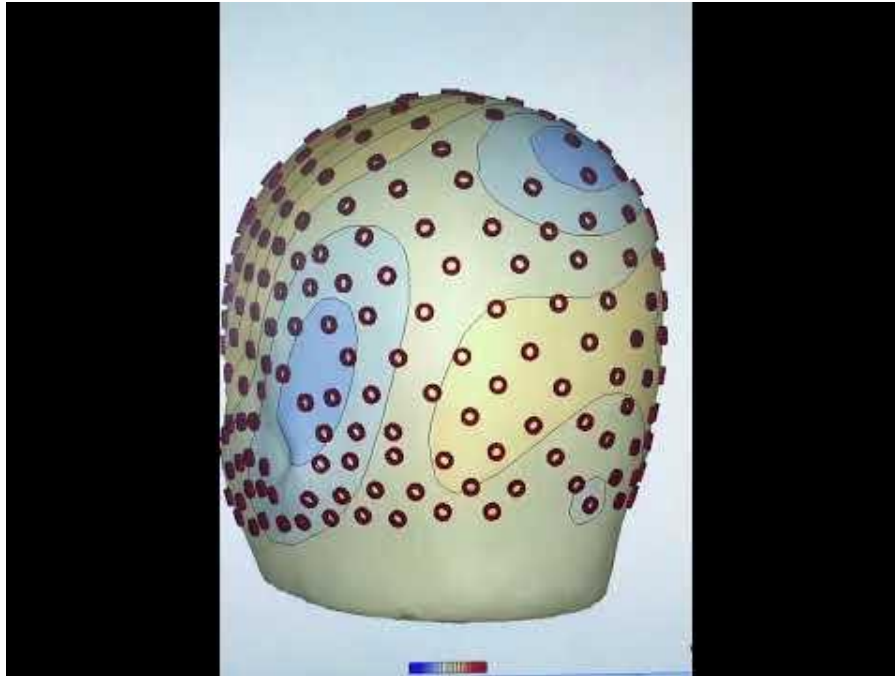

Figure 4. Video of the 3D head model showing an example of a 155 ms-lasting overlap of electrical transmission between auditory and visual sensory modalities, by scrolling over the specific part of EEG raw data in the reference free montage in BESA. The 3D model shows the back of the participant's head, turned laterally to the left, so that the contour of the left ear is visible to the viewer. The 155 ms long looming-related brain activity is expanded to a "slow motion", 10 s-lasting video for easier viewing. First, a light blue colour (negative voltage) appears around superior temporal gyrus/primary auditory cortex (electrode 7T), and in the upper parietal area (electrode Cz), before the colour gradually darkens, indicating a stronger build-up of negative voltage in these areas. These two meet in a slight overlap (light blue colour) at the same time as a gradual increase of blue colour occurs in the occipital area/V1 (electrode Oz). Electrical activity from T7 merges into the activation in Oz, which may indicate that V1 receives and integrates auditory information with already encoded visual information. An overlap then occurs between Oz and Cz, in which electrical activation in Oz progress upwards and ends in an even stronger activation in Cz before it eventually fades out. This may indicate that V1 passes integrated audiovisual information upward the dorsal stream, and then the audiovisual integration continues in the upper parietal area corresponding to Cz (Watch the video by clicking on the video, or on YouTube.com; https://www.youtube.com/watch?v=5bfk5JPwus8, uploaded 07.09.2022).

Together, the audiovisual loom triggered the brain in terms of independent VEPs in Oz/Pz or AEPs in Cz, but also in paths of audiovisual encountering, or overlapping, indicating audiovisual integration, or maybe better described as audiovisual evoked potentials (AVEP) in Oz/Pz and Cz (see Figure 5).
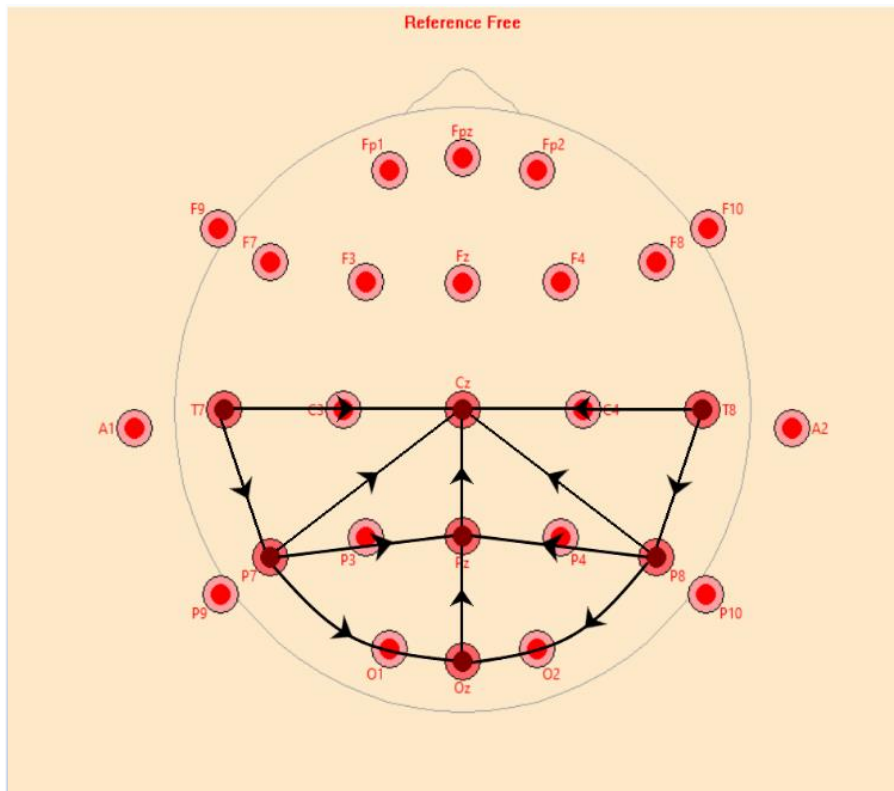
Figure 5. Distribution of the EEG electrodes according to the reference-free configuration including an illustration of moving pattern of pathways of looming-related brain activity. The activity went in a trajectory from T7/P7 and/or T8/P8 to Oz/Pz, or directly up to Cz. It was also observed that activity in Oz/Pz moved further up the dorsal stream and encountered the auditory activation in Cz.

In an attempt to count, it became clear that AVEP activation occurred more often in Oz/Pz across trials, than in Cz. The number of AVEPs extracted from the VEPs annotated from Oz/Pz was counted for both full-terms and preterms. Full-terms had 142 (*M*= 14, *SD*= 2.78) AVEPs counted, corresponding to 48% of the 298 (*M*= 30, *SD*= 5.09) VEP`s in Oz/Pz. For the preterm children, 139 AVEPs were counted (*M*= 14, *SD*= 6.92), corresponding to 44% of the 316 (*M*= 32, *SD*= 7.68) VEPs annotated.

3.2 VEP and AEP analysis at group level

The analysis of looming-related brain responses showed that for the full-term 6-year-olds, average looming-related VEPs occurred at a time-to-collision of -240 ms (*SD*= 0.07), and average AEPs occurred at a time-to-collision of -261 ms (*SD*= 0.10) before contact across looms. The prematurely born children showed earlier looming-related VEP responses in the looming sequence with at a time-to-collision of -423 ms (*SD*= 0.11), and AEPs occurring at a

time-to-collision of -314 ms (*SD*= 0.13), reflecting earlier brain responses in the looming sequence, and a with larger time gap between the modalities, than full-terms.

For the fast, medium, and slow looms, the full-terms showed average looming-related VEP responses of -231 ms (*SD*= 0.09), -239 ms (*SD*= 0.06), and -252 ms (*SD*= 0.06), respectively before collision, and looming-related AEPs at -248 ms (*SD*= 0.09), -256 ms (*SD*= 0.10), and -280 ms (*SD*= 0.10), respectively before collision. The preterms showed earlier looming-related VEPs at -436 ms (SD= 0.11), -408 ms (*SD*= 0.11), and -425 ms (*SD*=0.10), respectively before collision, and looming-related AEPs closer than their VEPs at -267 ms (*SD*= 0.12), -312 ms (*SD*= 0.12), and -364 ms (*SD*= 0.15), respectively before collision, and with higher variability as the speed of the loom decreased.

A 2 (Group: Term/Preterm) x 2 (Modality: VEP/AEP) x 3 (Loom speed: fast, medium, and slow) repeated measures ANOVA was conducted in order to test whether the preterms and full-terms showed their looming-related brain responses at different times-to-collision for the three loom speeds. *Group* was set as the between-subjects factor, and *Loom speed* and *Modality* were set as the within-subject factors. Bonferroni correction was performed to correct for multiple comparison.

The results showed a three-way interaction effect of *Modality*, *Loom speed* and *Group F* (2,36)= 3.96 , *p*< 0.01, indicating that both full-terms and preterms showed their average looming-related VEPs at a relatively fixed time-to-collision across looms, but the full-term children's VEPs were significantly closer to time-to-contact compared to the prematurely born children. Full-terms average looming related AEPs were significant closer to time-to-contact and relatively at a fixed time-to-collision, compared to the earlier AEPs of preterms which showed higher variance in terms of an increased time-to-contact with decreasing speed of the loom. Further, full-terms showed AEPs and VEPs at relatively equal time-to-collision, while the preterms' AEPs were significantly closer to time-to-collision than their VEPs, indicating a larger time gap between the modalities in preterms, compared to full-terms (See Figure 6).

The results showed a two-way interaction effect of *Modality* and *Group*, *F*(1,18)= 15.11, *p*= 0.001, indicating that the preterm children, on average, showed greater variance between their looming-related VEPs and AEPs, than the full-term children which showed VEPs and AEPs at relative equal time-to-contact.

Another two-way interaction effect between *Modality* and *Loom speed F*(2,36)= 5.50*, p*=

0.05, was found, indicating that the preterms showed higher variance in their average looming related AEPs than of their VEPs, across looms, whereas the full-terms VEPs and AEPs were relatively at fixed time-to-contact, independent of looms.

A significant main effect of *Group*, $F(1,18)= 37$, p< 0.,001, was found, indicating that the full-term children's looming related brain responses were closer to time-to-collision and more constant at a fixed time-to-contact, than preterms average brain responses.

A significant main effect of *modality, F*(1,18)= 6.99, *p*< 0.05, was found, but this was probably caused by the two-ways and three-ways interaction effects.

A significant effect of *loom speed*, $F(2,18)=6.55$, *p*< 0.05, was found, but this was probably caused by the twoways and three-ways interaction effects as well.
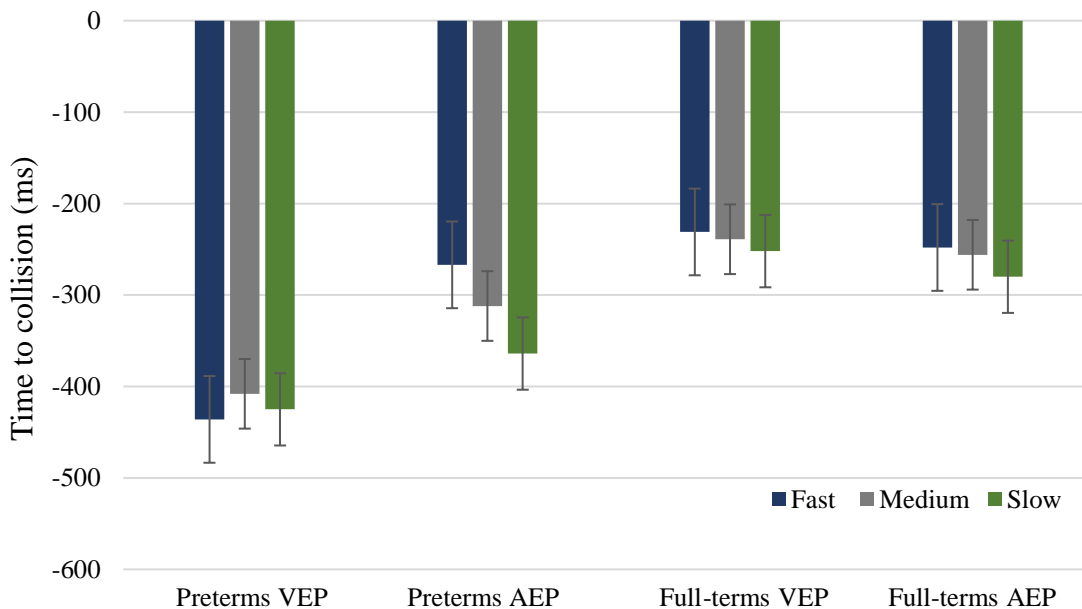
Figure 6. Average time-to-collision for looming-related VEP and AEP activation (including standard deviation bars), in electrode Oz/Pz (VEP) and Cz (AEP) for the three loom speeds (fast, medium, slow), for preterm and full-term children at 6 years of age. The full-terms showed their looming-related VEP & AEP responses significantly closer to collision compared to preterms. Full-terms show a trend of auditory activation, followed by visual activation in the looming sequence, while preterms show the opposite trend; visual activation followed by an auditory activation in the looming sequence. Both preterms and full-terms showed VEP values at relatively fixed time-to-collision, indicating the use of an efficient timing strategy based on time. However, preterms AEP responses increased with decreasing looms, indicating the use of a less effective timing strategy based on the loom's pitch, while full-terms AEP responses were relatively fixed on time-to-collision, indicating a timing strategy based on time. Thus, full-terms adopt matching timing strategies between modalities, while preterms do not, probably due to the larger time gap between the preterms modalities, compared to full-terms.

3.3 Button press analysis

The RMS values of button press responses were calculated to account for positive and negative timing errors, making the RMS values an indicator of timing error. The RMS values for the full-term group for the fast, medium, and slow looms were 158 ms ($SD= 80$), 196 ms ($SD= 90$) and 254 ms (SD= 74), respectively, with an average of 203 ms (SD= 60) across looms. For preterms the RMS values for fast, medium, and slow looms were 157 ms ($SD= 0.10$), 215 ms ($SD= 83$), and 276 ms ($SD= 75$), respectively, and an average RMS value of 216 ms ($SD= 60$) across loom speeds. (See Figure 7 and 8).

A 2 (Group) x 3 (Loom speed: fast, medium and slow) repeated measures ANOVA was conducted to test for possible differences between preterms at full-terms average RMS values (timing errors). *Group* was set as between-subjects factor and *Loom speed* as within-group factor. Bonferroni correction was performed.

A main effect of *Loom speed* was found $F= (2, 36)$ 37.17, $p < 0.001$, indicating that the RMS values increased with increasing looms for both preterm and full-term children.

The results showed no significant effect of *Group* and *Loom Speed* ($p= 0.615$), indicating that the preterm and full-term children had relatively equal timing errors across loom speeds.

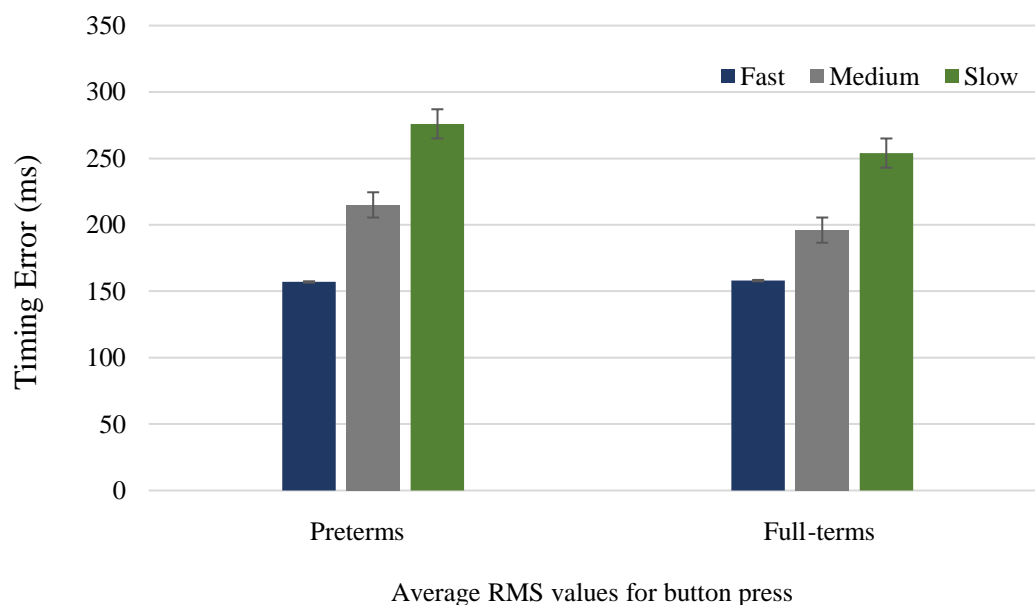
Average RMS values for button press

Figure 8. Average timing errors (RMS) with SDs for the three looming speeds, among preterm and full-term 6-year-olds. On average the children show relative equal pattern of timing their motor responses, as their RMS values are at relatively equal time to contact, and with increasing RMS values with decreasing looming speed.
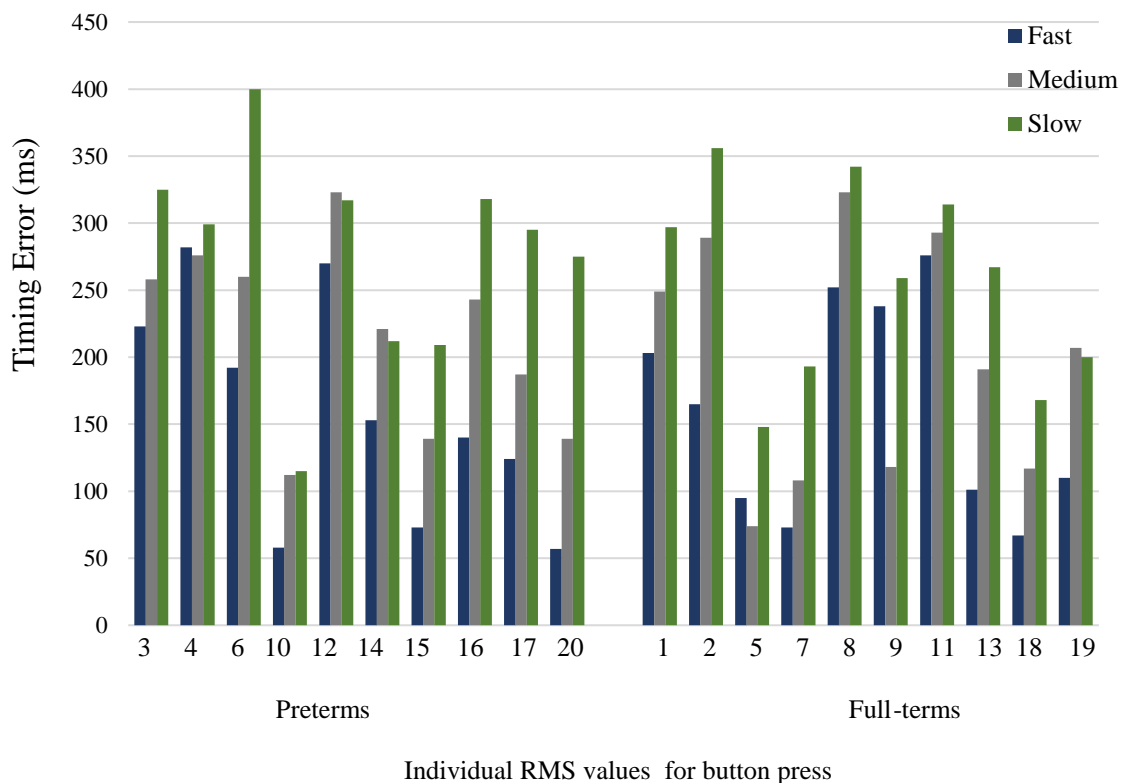
Figure 8. Individual button press timing errors (RMS values in ms) for fast, medium and slow looms among preterm and full-term 6-year-old children, referenced by participant number. Most children show increasing RMS values of BP responses with decreasing loom speed. Preterm child number 6 stands out with the highest variability in RMS values across loom speeds of all children. Preterm child nr. 10 and full-term child nr. 5 stands out with the smallest RMS values, regardless of loom speed, compared with the rest of the sample. Preterm child nr. 12 and full-term child nr. 8 stands out with the largest RMS values, regardless of speed. Overall, there appears to be relatively equal variance between preterms and full-terms.

3.4 Motor Performance analysis: Movement ABC scores

In Table 1, the children's score, separated by group affiliation; preterm and full-term, from the Movement ABC test is shown. Two full-term and two preterm children had a total score above 13.5, indicating a possible delay in motor development. A two-tailed t-test showed no significant difference ($p=.723$) in average motor performance between the preterm ($M=8.75$, $SD=7.36$) and full-term ($M=7.8$, $SD=5.64$) children.

M-ABC Scores									
PT	Manual Dexterity	Ball Skills	Static/ Dynamic Balance	Total score	FT	Manual Dexterity	Ball Skills	Static/ Dynamic Balance	Total score
3	13	5	3	21	**1**	10	3	1.5	14.5
4	3.5	0	4	7.5	**2**	9	1	2	12
6	9	4	9	22	**5**	0	0	0	0
10	5	0	0.5	5.5	**7**	0.5	0	1	1.5
12	8	1	4	13	**8**	5	3	1	9
14	4	0	0	4	**9**	4	0	0	4
15	1	2	0.5	3.5	**11**	11	0	2	13
16	4	0	4	4	**13**	7	3	1	11
17	2	0	0	2	**18**	0.5	2	0	2.5
20	1.5	3	0.5	5	**19**	15	2	0	17

Table 1. Individual scores of motor performance on the M-ABC test between 10 full-term (FT) and 10 prematurely born (PT) children at 6 years of age, referenced by participant number. A total score higher than 13.5 (highlighted) indicate a possible motor delay. The high scores appeared to mainly apply to Manual Dexterity related to fine motor skills.

4. Discussion

This study investigated differences between 10 full-term and 10 prematurely born 6-year-olds in cortical and behavioural responses to an audiovisual looming stimulus approaching at three different speeds, using HD-EEG. Looming-related AEP and VEP time-to-collision values were used as a measure of cortical responses. Button presses were recorded as behavioural responses to the approaching audiovisual looms. The children's motor skills were also tested, using Movement Assessment Battery for Children (M-ABC). The results suggested that, in comparison to full-terms, preterms have problems with audiovisual perception of the loom, and may be compensating auditorily for an impaired visual motion perception. Further, the results from behavioural analyses indicated relatively equal variance in motor skills between preterm and full-term children. This may point to limitations with motor behaviour tests' ability to detect perceptuomotor deficiencies among preterms who do not have known neurological deficits such as cerebral palsy or retinopathy associated with prematurity.

Prominent VEPs and AEPs were observed in the occipital (Oz/Pz) and parietal (Cz) brain areas, respectively. These findings are consistent with previous research pointing to the relevance of these cortical locations (e.g., Tyll et al., 2013). Nevertheless, knowing that studies on infants show AEPs earlier than VEPs in the looming sequence (Agboada, 2013; Saeed, 2018), it was somewhat surprising to observe a recurring pattern of prominent AEPs happening closer to time-to-collision than of the VEPs, across trials among most children. In the subsequent statistical analysis, it became evident that these observations mainly applied to the preterm children which will be discussed in more detail later on.

This study is the first within the looming paradigm to report electrical overlap between auditory and visual modalities as a sign of audiovisual integration in 6-year-olds. Previous studies on 6-year-olds investigated visual motion perception and did probably not devote attention to any electrical overlap between the visual and auditory modalities during visual scanning of the EEG data (e.g., Vilhelmsen et al., 2021). Interestingly, our results show patterns of electrical activity were observed in a trajectory from superior temporal sulcus /A1 (T7/P7 and/or T8/P8) to visual cortex (Oz/Pz), or directly up to upper parietal brain areas (Cz), corresponding to cortical areas of the dorsal stream (Cappe et al., 2012; Tyll et al., 2013).

Electrical overlap may be seen as a potential problem because it can create difficulties with precise measurements of the timing of the individual ERP, as ERPs often overlap with their

neighbours in time and place (Woodman, 2010). However, this study operates with two sensory modalities, during exposure to a (synchronous) moving audiovisual loom, where it is not expected that both modalities are activated equally in terms of time or place (e.g., Saeed, 2018; Tyll et al., 2013). Hence, in this study, no problems were encountered in terms of detecting location, or registration of time-to-collision values. And what makes the observations interesting is that it illuminates moving electrical activity as reliable patterns across sessions of all participants. The observations of moving electrical encountering, or overlapping, may point to looming related audiovisual integration (AVEP), where the main proportion was observed in V1 in both preterms and full-terms. This is compatible with previous findings of superior temporal sulcus receiving information from visual and auditory regions, as well as it being crucially involved in the perceptual binding of audiovisual information (for review, see Tyll et al., 2013). The observations are also compatible with the notion that cross-modal integration can be extended to the low-level primary sensory areas (Meijer et al., 2017; McCracken, & Neuhoff, 2021).

Further, our results indicate that the 6-year-old brain has more functional pathways, and can switch between these, involving larger parts of the brain for electrical transmission, than the 1-year-old brain, as there have been no reported observations of overlapping electrical brain activity between the sensory modalities of 1 year-olds (Agboada et al., 2015; Saeed, 2018). This may be because the infant brain is at a much earlier stage in the pruning process and has less experience with changing environments than the brain of the 6-year-old (Webb, et al., 2005; Constable et al., 2008). Hence, the infant brain does not have as specialized neural pathways, resulting in rather centralized looming related brain responses with no electrical overlapping between sensory modalities (Agboada et al., 2015; Saeed, 2018). Audiovisual integration should become more coordinated in time with age, given that the goal is to develop efficient and accurate strategies when dealing with the surroundings (e.g., Agboada et al., 2015). In such case, auditory and visual brain activity would not present themselves as independent units, but rather in a stronger resonance with each other, which the electrical overlaps between modalities in the 6-year-old brain may indicate.

Our observations indicate that brain areas corresponding to electrodes Oz/Pz and Cz may operate with auditory (AEP) and visual (VEP) information separately, and simultaneously (AVEP). However, the terms VEP and AEP will be used from now on, with respect to which sensory information the modalities are known to spend the most resources on (e.g., Meijer et al., 2017). Our results showed that full-term children's average looming related VEPs and

AEPs were closer to time-to-collision than those of the preterm children, suggesting that premature children process audiovisual looming information slower than full-term children. Preterms` early brain responses may be due to problems with myelination in the prematurely born brain (Kelly et al., 2016; Constable et al., 2008; Weinstein et al., 2012), which leads to impaired functional integrity in terms of less precisely timed signal transmission in response to external information (e.g., Van der Meer et al., 2012).

Full-terms showed VEPs and AEPs at relatively equal time-to-collision, while preterms' AEPs were shown to be significantly closer to time-to-collision than their VEPs. First, full-term children, showed the same trend with AEP before VEP in the looming sequence, as found in infants (Agboada et al., 2015; Saeed, 2018), although their AEPs and VEPs at the age of 6 seems to be relatively equal in time. The findings are compatible with previous research pointing to vision as the primary sensory source during audiovisual motion perception (DeLucia et al., 2016; Zhou et al., 2007), and the functionally role of the auditory as a warning system for the visual (Leo et al., 2011; Regan & Vincent, 1995). Further, the relatively equal time-to-collision values of the modalities among the full-term 6-year-olds, compared to full-term infants, may indicate the continuance of a developmental trend of multisensory integration becoming more coordinated in time with age (Agboada et al., 2015).

Further, it became evident that VEPs earlier than the AEPs in the looming sequence, with or without electrical overlaps, was most frequently observed in the prematurely born brain. This was somewhat surprising, as we expected preterms to also show AEPs earlier than their VEPs, based on previous research (e.g., Regan & Vincent, 1995; Leo et al., 2011). However, hearing develops earlier than vision during the fetal stage (Graven & Browne, 2008) and may therefore not be disturbed by premature birth to the same extent as vison (e.g., Delafield-Butt et al., 2018). Hence, the auditory modality may have switched places with the visual and become the primary source in preterms audiovisual motion perception. One can argue that the prematurely born child may, based on experience, trust their brain`s ability to process auditory information to a greater extent, similarly to a blind person strongly relying on other sensory information in the absence of visual information (Amedi, Merabeth, Bermpohl & Pascual-Leone, 2005). Hence, the preterm brain makes use of the most effective system(s) it has at its disposal to be able to perform successful actions in relation to the surroundings.

Both full-terms and preterms showed average looming-related VEPs at a relatively fixed time-to-collision across fast, medium, and slow loom speeds, indicating the use of the

efficient timing strategy based on time. These findings are consistent with previous research on 6-year-olds (e.g., Vilhelmsen et al., 2021), as well as the expected ability of the visual modality to make precise temporal estimations (Regan & Vincent, 1995). But that does not necessarily help with the fact that early VEP responses, as shown by the preterm children, may potentially create problems in estimating the loom's collision time (e.g., Van der Meer et al., 2012).

It appears that the bi-directional influence between the visual and auditory modalities of preterms is not working as it should. Preterms showed higher variance in their average AEPs in terms of increasing time-to-collision values with decreasing loom speed, indicative of a less efficient timing-strategy based on pitch (e.g., Agboada et al., 2015). Full-terms, on the other hand, showed average AEPs at a relatively fixed time-to-collision, independent of loom speed, indicative of an efficient timing-strategy based on time (e.g., Van der Meer et al., 2012). In other words, full-terms adopt matching timing strategies between modalities, while preterms does not. This may indicate that the visual information with more precise temporal estimates influence, or even better, corrects the bias from the less reliable auditory modality in an audiovisual integration in the normally-developed brain (McCracken, & Neuhoff, 2021). In the preterm group, this does not seem to occur, probably due to a larger time gap between their AEPs and VEPs, compared to full-terms, thus resulting in a potentially impaired, or incomplete, audiovisual motion perception.

However, no significant differences regarding BP timing errors were found between the groups. Further, both preterm and full-term children showed increasing timing errors with decreasing loom speed. These results do not show the typical pattern proper of a speed-accuracy trade-off principle which states that during the performance of a motor response, people tend to favour either accuracy or speed of the response according to the demands of the task. Thus, if speed is favoured, it will end up negatively affecting the accuracy, and vice versa (Schmidt, 1982). A principle referred to as the velocity effect makes an exception of this rule as it states that timing accuracy of a motor response increases when the average movement time decreases, and average velocity increases (Newell et al., 1979; Schmidt, 1982). If a task gives little time to carry out a motor response, such as the stimuli of this present study, aiming to respond quickly might increase the chances of timing the response in a more consistent manner. Thus, timing error increasing with decreasing loom speed shown among most of the children in this present study may reflect the velocity effect. Some children did not show timing errors consistent with the velocity effect. However, they showed

less response variability in the fast and medium speeds than in the slow one, which may still be in line with the velocity effect.

Pre-term and full-term continued their similarities in motor skills when the results from the M-ABC also showed no significant differences between the groups. Four children, two preterm and two full-term, showed scores above 13.5, indicating motor problems (Henderson & Sugden, 1992). However, before making any conclusion, one should consider these results together with other confounding variables. For example, premature child nr. 6 and full-term child nr. 1 with a score above 13.5 had not yet reached the age of 6 and may therefore have had greater difficulties with completion than the others. Further, both of them tested the system during test session and the results could be affected by lack of motivation or attention. The second preterm child (nr. 3) with a score above 13.5 was born in gestational week 31 with low weight (1400 g), which is found to heighten the risk of complications with motor performance (e.g., MacKay et al., 2005; Braddick et al., 2003). However, this child mainly struggled with manual dexterity tasks, which may indicate impairment in fine motor skills. The second full-term child did not stand out on either birth weight, age, nor motion perception based on EEG results of this study; hence a possible explanation may lie in other, unknown internal/external variables around the child which should be investigated further before a conclusion is finalised.

Nevertheless, the discrepancy between the results at the brain and behavioural level (BP) may be explained by preterms making use of auditory information to compensate for deviant visual motion perception, reminiscent of a survival strategy to ensure successful prospective actions in line with full-term children. A similar conclusion may be drawn when it comes to zero findings of group differences on the M-ABC as well. Also, M-ABC's inability to detect perceptuomotor problems in preterms who do not suffer from a more serious neurological abnormality, such as Cerebral Palsy, is known from previous research (Rodríguez, 2021; Aanondsen et al., 2007). Although a potential coping mechanism among the preterm gives promising results in the form of relatively similar performances on motor tasks, it does not come without potential problems.

Problems with an auditory motion perception to bear the primary responsibility for temporal predictions arise as this is not considered the primary role/functionality of the modality (e.g., DeLucia et al., 2016; Regan & Vincent, 1995), as well the auditory system being more prone to bias than the visual system due to, for example, poor physiological foundation

(McCracken & Neuhoff, 2021), such as poor myelination (e.g., Hammarrenger et al., 2003; Constable et al., 2008; Weinstein et al., 2012). Our findings indicate that the auditory system of the premature children is biased in its temporal estimations by showing earlier time-to-collision values and the use of a lesser efficient timing strategy, compared to full-terms. Due to a limited bi-directional influence, as suggested by our findings, the auditory system does not seem to receive sufficient help, or corrections from the visual, and stands relatively alone in temporal estimations of the loom. This raise concerns regarding preterms safety in real-life situations more dangerous than the laboratory setting, where they have to plan and perform precisely-timed movements to avoid injury. Furthermore, one can also raise questions about whether the compensatory function of the auditory system comes at the expense of something else, such as energy use of the brain.

Perhaps it has become clear that future research should focus on achieving a greater understanding of the premature brain. A possible way to explore this further could be to conduct a Temporal Spectral Evolution (TSE) and Coherence connectivity analysis. A recent study on preterm and full-term 6-year-olds, use these analysis tools to investigate visual motion perception in a timing task consisting of stopping a temporarily occluded car moving at three different speeds in a designated target area (Kristoffersen, 2022). Their TSE findings showed gamma desynchronization in the preterm brain and gamma synchronization in the full-term brain during exposure to visual motion. The gamma desynchronization may indicate that preterms perceive the visual information as more complex and needed a higher degree of effort and attention throughout the experiment, in comparison to full-terms, probably due to white matter abnormalities (for review, see Kristoffersen, 2022). As it was not an audiovisual experiment, the synchrony in frequency bands in the auditory modality is yet to be discovered. Considering the findings from this present study, one may hypothesize that the TSE analysis would point towards a higher level of synchronization in the auditory modality versus the visual modality, in preterms. At the same time, it is likely that full-terms show relatively equal synchronization between auditory and visual modalities, as well as a higher degree of synchronization than preterms in general, under the exposure of an audiovisual loom.

Further, Kristoffersen's (2022) results showed a stronger connectivity in full-term than preterm, across motion conditions. This indicates a better establishment of functional pathways for signal transmission, flexible to different visual motion conditions in the full-term brain, compared to the preterms who seems to have less established functional pathways

and hence also less flexibility (Kristoffersen, 2022). Considering the plasticity of the brain, a disrupted functional pathway calls for alternate systems to compensate for conventional circuit failure (Shaywitz et al., 2002), compatible with the findings of this present study. Hence, a connectivity analysis within the (audiovisual) looming paradigm can provide further answers to the auditory modality's compensatory role, proposed by our findings, as a result of structural and functional impairments of the visual.

Plasticity is what underlies development and learning, but it may also be a potential cause of pathology and not lead to behavioural gain (Amedi et al., 2005). Early interventions that modulate neural plasticity in preterm individuals, for example by audiovisual brain-stimulation techniques may aid preterms audiovisual integration and motion perception development.

5. Conclusion

This study investigated differences between full-term and prematurely born 6-year-olds in cortical and behavioural responses to an audiovisual looming stimulus approaching at three different speeds, using HD-EEG. During visual scanning, some interesting findings were made of moving electrical activity in overlap between superior temporal sulcus/A1 to visual cortex and/or upper parietal brain regions, indicative of audiovisual integration. However, the results from statistical analyses suggest that preterm children have poorer audiovisual integration and compensates auditorily for an impaired visual motion perception. Even if the premature brain valiantly manages to create an alternative that enables successful prospective actions, we cannot ignore the shortcomings of the auditory modality's temporal predictions, as it is not considered its primary functional role. This cause concerns for preterms safety, when engaging with daily environmental demands. Furthermore, it raises questions about whether an auditory compensatory system is beneficial for the brain, or if it comes at the expense of something else. Hence, further research will be needed to provide greater functional understanding of the premature brain. We join the ranks of researchers who encourage early interventions for premature babies, already in first year of life, to minimise potential long-term effects of prematurely birth.

6. References

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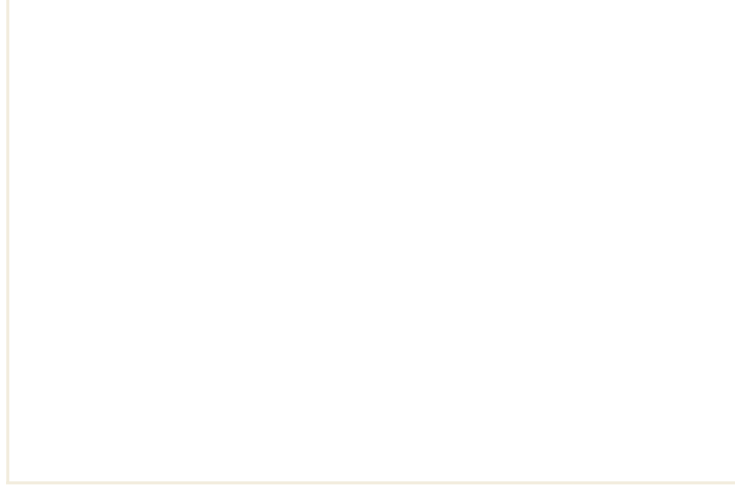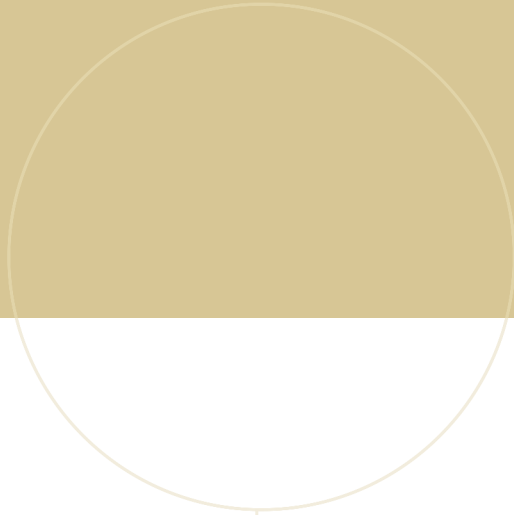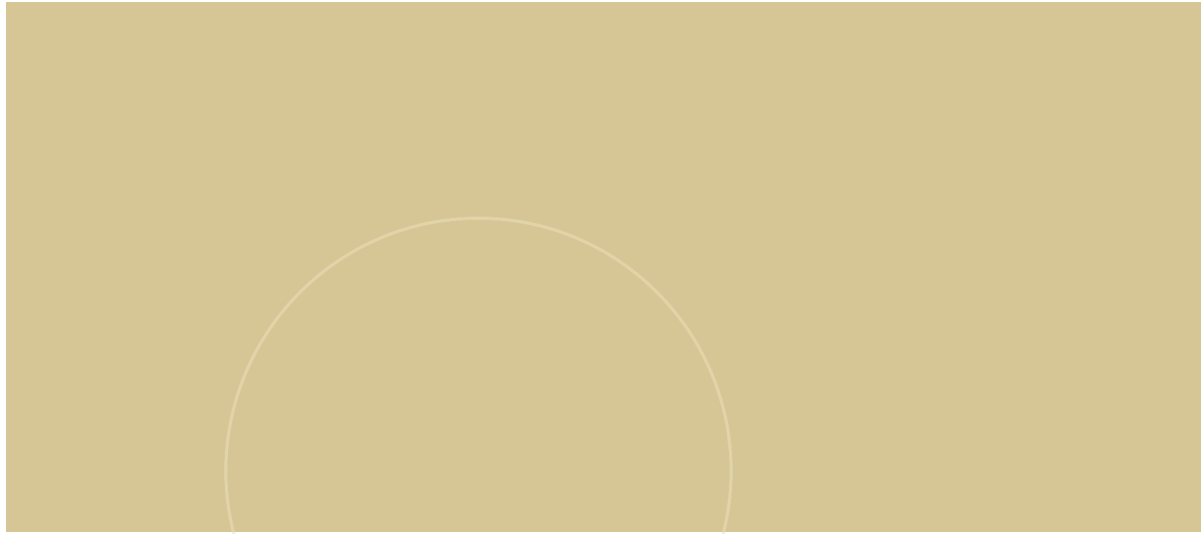density EEG study.* (Master's thesis, NTNU).

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